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EVALUATION PROGRAM
for
SECONDARY SPACECRAFT CELLS

EVALUATION OF STORAGE METHODS
OPEN CIRCUIT VERSUS CONTINUOUS TRICKLE CHARGE
SONOTONE 3.5 AMPERE-HOUR SEALED NICKEL-CADMIUM
SECONDARY SPACECRAFT CELLS

prepared for
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QUALITY EVALUATION LABORATORY

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1. In compliance with reference (a), enclosure (1) is forwarded for information and retention.

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EVALUATION PROGRAM
FOR
SECONDARY SPACECRAFT CELLS

EVALUATION OF STORAGE METHODS, OPEN CIRCUIT VERSUS CONTINUOUS TRICKLE CHARGE, SONOTONE 3.5 AMPERE-HOUR SEALED NICKEL-CADMIUM SECONDARY SPACECRAFT CELLS

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REPORT BRIEF
EVALUATION OF STORAGE METHODS
OPEN CIRCUIT VERSUS CONTINUOUS TRICKLE CHARGE, SONOTONE 3.5 AMPERE-HOUR SEALED NICKEL-CADMIUM SECONDARY SPACECRAFT CELLS

Ref: (a) National Aeronautics and Space Administration Purchase Order Number W12,397
(b) NASA ltr BRA/VBK/pad of 25 September 1961 w/BUWEPS first end FQ-1:WSK of 20 October 1961 to CO NAD Crane
(c) Preliminary Work Statement for Battery Evaluation Program of 25 August 1961

I. TEST ASSIGNMENT BRIEF

A. In compliance with references (a) and (b) evaluation of methods for storage of nickel-cadmium cells at room ambient conditions was begun on 27 February 1966 according to the program outline of reference (c). The nickel-cadmium cells used for this test were 3.5 ampere-hour "D" cells manufactured by the Sonotone Corporation.

B. The overall object of these evaluation programs is to gather specific information concerning secondary spacecraft cells. Information concerning performance characteristics and limitations including cycle life under various electrical and environmental conditions will be of interest to power systems designers and users. Cell weaknesses, including causes of failure of designs, will be of interest to suppliers as a guide to product improvement.

C. The specific purpose of this 5-year test is to compare, after each successive 1-year storage period, the discharge and charge characteristics of charged cells on open circuit versus that of cells on continuous trickle charge.

D. Of the original 25 cells subjected to the acceptance tests, 20 were selected for this storage test. Following recharge, after completion of the acceptance tests, 10 cells were placed on open circuit stand and 10 were placed on continuous trickle charge at the c/100 rate.

E. Following completion of each year of storage, the cells were subjected to the standard acceptance test sequence. However, no cells were rejected or removed from the storage test on the basis of this testing sequence. These tests, after each year of storage, serve as a means of reporting the condition of the cells as the test continues and aids in the selection of a cell of lower capacity of each storage method for analysis at the end of each yearly storage period.

1. Data of the acceptance test sequence following completion of the fourth 1-year storage period is contained in this report accompanied by summaries and data accumulated from the start of the storage testing.

2. Following removal of one cell of each storage method after each 1-year storage period, the remainder of the cells were recharged and shelved for the fifth and final 1-year storage period.

II. CONCLUSIONS

A. The results of the first 4 years of this storage test show the following:

1. The initial capacities of charged cells following the first, second, third and fourth 1-year open circuit periods are unreliable. They varied from zero to 62 percent of the average acceptance capacity as determined before the start of the storage testing.

2. The initial capacities of charged cells following the first, second, third and fourth 1-year trickle charge storage periods are reliable. They averaged 78, 75, 84, and 77 percent respectively of the average acceptance capacity as determined before the start of the storage testing.

3. Conversely, the second and third discharge capacities of cells following successive yearly open circuit storage periods are reliable, and averaged considerably higher than the capacities of cells following the first 2 years (only slightly higher the third and fourth years) of trickle charge storage. The capacities of the open circuit storage tests following recharge continue to be slightly greater than those of the trickle charge tests. However, this difference has declined each year thus far.

4. The open circuit recovery voltages for cells on the fourth 1-year open circuit storage period were zero for each of the remaining seven cells. However, the recovery voltage of cells on the fourth 1-year trickle charge period average 1.20 volts.

5. Postmortem analysis on the cell removed from the open circuit storage test showed that the electrolyte was not uniformly distributed. The separator material was very dry and less pliable

than cell on trickle charge storage test. It also showed one small brown discoloration on separator material near center of roll and the seperator material adherence to the cadmium plate was severe. In the wet portions the migration was more extensive. This indicates that only the wet portions of the cell are being worked--resulting in lower capacity. This further indicates that briefly cycling the cells on open circuit storage would likely restore capacity by redistributing the electrolyte. Thus a portion of the overall capacity difference noted in the previous paragraph would be restored. Postmortem analysis also indicates that reconditioning cycles would be unlikely to revitalize the cells on the trickle charge storage test. This is due to more general migration and visible degradation observed in these cells. The cell on the trickle charge storage test showed pin holes of missing active material within a diagonial crease of inner portion of the positive plate.

B. The ceramic seals of these cells revealed seven leakers for the open circuit storage cells and six leakers for the trickle charge storage cells. These 13 leakers out of the 14 cells on test were an increase over the third 1-year storage period. The completion of the third 1-year storage was the first indication of leakers.

EVALUATION OF STORAGE METHODS, OPEN CIRCUIT VERSUS CONTINUOUS TRICKLE CHARGE, SONOTONE 3.5 AMPERE-HOUR SEALED NICKEL-CADMIUM SECONDARY SPACECRAFT CELLS

I. INTRODUCTION

A. On 8 August 1970, tests were begun on 14 cells following the fourth 1-year storage period. The testing sequence was completed on 26 August 1970; two cells were removed for postmortem analysis; and the remaining 12 cells were returned to their respective storage tests.

II. TEST CONDITIONS

A. All tests were performed at an ambient temperature between 23° C and 27° C at existing relative humidity and atmospheric pressure, and consisted of the following:

1. Phenolphthalein Leak Test.
2. Capacity Test.
3. Cell Short Test.
4. Immersion Seal Test.
5. Overcharge Test.
6. Internal Resistance Test.
7. Immersion Seal Test.
8. Visual Postmortem.

B. All charging and discharging were done at constant current (± 5 percent). Cells were charged in series but discharged individually.

III. CELL IDENTIFICATION AND DESCRIPTION

A. The cells were identified by the manufacturer's serial numbers which were from A-2491 to A-2551 although not consecutively.

B. The 3.5 ampere-hour "D" cell is cylindrical with an average diameter of 1.306 inches and an average overall length of 2.387 inches including the positive terminal. The average weight was 158.8 grams. Figure 1 is a photograph of a Sonotone Corporation 3.5 ampere-hour "D" cell.

C. The cell container or can, and the cell cover are made of stainless steel. A stainless steel tab, welded to the cover, serves as a contact for the negative terminal. The positive terminal is a solder type extension of the positive plate tab, through the center of the cover. The positive terminal is insulated from the "negative" cover by a ceramic seal. Two crimp rings, about 1/32 inch deep, located about 9/16 inch from each end of the cell, were crimped after assembly to hold the element snugly in the can to withstand vibration.

D. These 14 cells, rated by the manufacturer at 3.5 ampere-hours, have completed four 1-year storage periods at 25° C. Seven of the cells have been on open circuit stand during the last year in the charged state. The other seven cells have been on continuous overcharge during the last year at the c/100 rate (35 milliamperes).

IV TEST PROCEDURE AND RESULTS

A. Phenolphthalein Leak Test:

1. The phenolphthalein leak test is a determination of the condition of the welds and ceramic seals prior to any electrical tests. This test was performed with a phenolphthalein spray indicator solution of one-half of one percent concentration.

2. Following the fourth 1-year storage, the group of cells on yearly open circuit gave evidence of seven leakers; the group on yearly trickle charge gave evidence of six leakers. All leaks occurred around the positive post. This was the second indication of leaks.

3. Table I gives a summary of the noted leakers.

B. Capacity Test:

1. Upon receipt, the cells were subjected to the acceptance tests which included three capacity checks. The capacity test is a determination of the cell capacity at the c/2 discharge rate, where c is the manufacturer's rated capacity, to a cutoff voltage of 1.00 volt per cell.

a. The discharge of each of the three original capacity checks followed a 1-hour open circuit period after a 16-hour charge at the c/10 rate.

b. For the series of three capacity checks following each 1-year period of the respective storage method, the first consisted of an immediate discharge to 1.00 volt per cell at the c/2 rate. The second and third capacity discharge checks followed a 1-hour open circuit period after a 16-hour charge at the c/10 rate.

2. Open Circuit Storage Test:

a. The capacities of the first capacity check of the 10 cells picked for the 1-year open circuit storage periods averaged 3.90 ampere-hours. This was used as 100 percent capacity for the start of the test. All following capacities or averages thereof are plotted on the graphs as percentages of the initial average capacity. Following recharges, the second and third capacity checks averaged 3.80 and 3.61 ampere-hours for 97.5 and 92.5 percent respectively of the first capacity test.

b. Following the fourth 1-year stand (1970), the seven cells remaining, after three yearly postmortem removals, were discharged to 1.00 volt per cell at the c/2 rate. This first of three capacity checks resulted in capacities ranging from 0.0 to 0.671 ampere-hours for an average of 0.096 or approximately 0.03 percent of the initial capacity. The capacities of the second and third capacity checks, following recharges, averaged 3.24 and 3.08 ampere-hours respectively for approximately 83.0 and 78.9 percent of the initial capacity. In 1967 these respective averages were 41.5, 90.8, and 84.6 percent of the initial capacity. In 1968 the percentages were 30.7, 80.0, and 76.8. In 1969 the percentages were 1.0, 77.9, and 68.2 percent of initial capacity.

c. The preceding information shows that the initial capacities of charged cells left on 1-year open circuit stands at 25° C are unreliable. However, the capacities of these cells, following recharges after the first 1-year open circuit stand are all high--averaging 84.0 percent of the initial capacity on the third capacity check. The second and third 1-year stands (with one low capacity exception each year) also displayed good capacities--averaging 76.0 and 78.0 percent of initial capacity, each respective year, on the third capacity check. The fourth 1-year stand displayed good capacity--averaging 78.9 percent of the initial capacity, on the third capacity check.

d. The capacity test data of cells on successive 1-year open circuit storage periods is given in Table II and shown graphically in Figure 2.

3. Trickle Charge Storage Test:

a. The capacities of the first capacity check of the 10 cells picked for the 1-year trickle charge storage periods averaged

3.92 ampere-hours. This was used as 100 percent capacity for the start of the test. All following capacities or averages thereof are plotted on the graphs as percentages of the initial average capacity. Following recharges, the second and third capacity check averaged 3.81 and 3.59 ampere-hours for 97.2 and 91.6 percent respectively of the first capacity test.

b. Following the fourth 1-year trickle charge storage period (1970) and following a 1-hour open circuit period, the seven cells remaining, after three yearly postmortem removals, were discharged to 1.00 volt per cell at the c/2 rate. The first of the three capacity checks ranged from 2.25 to 3.59 ampere-hours for an average of 3.03 ampere-hours or 77.3 percent of the initial capacity. The capacities of the second and third capacity checks, following recharges averaged 3.07 and 2.84 ampere-hours respectively for 78.2 and 72.5 percent of the initial capacity. In 1967 these respective averages were 78.0, 62.5 and 62.5 percent of the initial capacity. In 1968 the percentages were 74.5, 66.5 and 72.7 percent of the initial capacity. In 1969 the percentages were 84.2, 72.7 and 67.3 percent of the initial capacity.

c. The preceding information shows that the initial capacities of charged cells left on yearly trickle charge storage periods at the c/100 are still highly reliable after 4 years of such storage. Further the trickle charge method of storage still tends to give less capacity than the open circuit method following recharges; but the difference in capacity between these two storage methods is less each year. Compare the average and percentage data for the two storage methods in Table II. Notice, the percent of initial capacity for the second and third capacity checks continually shows less difference between the storage methods as time proceeds.

d. The capacity test data of charged cells on successive 1-year trickle charge storage periods is given in Table II and shown graphically in Figure 3.

C. Cell Short Test:

1. The cell short test is a means of detecting slight shorting conditions which may exist in a cell because of imperfections in the insulating materials, or damage to element in handling or assembly; or which may develop in cells due to deterioration of the insulation materials during service life.

2. Following completion of the third capacity discharge test, (prior to the start of each yearly storage period), each individual cell was loaded with a resistor of value 0.5 ohms, 10

watt, giving a c/1 to c/5 discharge rate. Each cell was allowed to stand 16 hours with the resistor acting as a shorting device. At the end of 16 hours, the resistors were removed and the cells allowed to stand on open circuit for 24 hours. Under the regular acceptance test procedure used prior to start of the first 1-year storage period, any cell whose voltage did not recover to a minimum of 1.15 was rejected. However due to the nature of this series of successive 1-year storage periods, cells with recovery voltages less than 1.15 after each yearly storage period are not rejected or removed from succeeding tests.

3. The recovery voltages for the cells, prior to the start of the storage test, ranged from 1.21 to 1.24 volts for an average of 1.22 volts per cell.

4. The recovery voltages for the cells after the first 1-year period under either storage method averaged 1.21 volts per cell.

5. Following the second 1-year open circuit storage period, the open circuit voltage of each of two cells failed to recover significantly above zero volt. However, the recovery voltage of cells following the second 1-year trickle charge storage period average 1.21 volts.

6. Following the third 1-year open circuit storage period, the open circuit voltage of each of two cells was zero. However, the recovery voltage of cells following the third 1-year trickle charge storage period again averaged 1.21 volts.

7. Following the fourth-year open circuit storage period, the open circuit voltage of each of four cells was zero. However, the recovery voltage of cells following the fourth 1-year trickle charge period averaged 1.20 volts.

8. The recovery voltages values following the cell short test are given in Table III.

D. Immersion Seal Test:

1. The immersion seal test is a means of detecting leakage of a seal or weld. The test was performed before and after the overcharge test during the acceptance test sequence prior to start of each 1-year storage period to determine the presence and cause of leaks.

2. The cells were placed under water in a bell jar container. A vacuum of 20 inches of mercury was held for 3 minutes. Tests are to be discontinued on cells discharging a steady stream of bubbles.

3. There were no detectable leaks by this method after the fourth 1-year storage period. However phenolphthalein tests gave leak indications as explained in paragraph IV.A.2. and summarized in Table I.

E. Overcharge Test:

1. The overcharge tests were performed to determine the steady state voltage at specified rates. The test specified a series of three successive constant current charges at the c/20, c/10 and c/5 rates in order. The charge at each rate was for a minimum of 48 hours or until the increase of the on-charge voltage was less than 10 millivolts per day. Upon completion of 48 hours of charge at each of the lower rates, the charge rate was increased to the next higher specified rate. These tests were performed prior to start of the storage test, and after each successive yearly storage period under each storage method.

2. The cells were monitored hourly throughout the overcharge test. Under regular acceptance testing, the test procedure requires that charging be discontinued on cells which exceed 1.50 volts, the maximum specified on-charge voltage. However, for this test, charging of a few cells was discontinued when their on-charge voltages exceeded the revised voltage limit of 1.55 but none were rejected or removed from the test.

a. During the overcharge test prior to the first 1-year storage period, charging was discontinued on two of the 20 cells when the voltage exceeded 1.55 volts after 10 hours at the c/5 rate.

b. During the overcharge test after the first 1-year storage periods:

(1) Only one of the open circuit stored cells exceeded 1.55 volts at the c/10 rate. It was removed from the charging circuit after 7 hours of charge, and was not subjected to overcharging at the c/5 rate.

(2) The highest on-charge cell voltage reached by trickle charge stored cells was 1.42 while charging at the c/5 rate.

c. During the overcharge test after the second 1-year storage periods:

(1) Only two of the open circuit stored cells exceeded 1.55 volts for a few hours. The cells were allowed to continue the overcharge sequence and did not exceed 1.55 volts at either the c/10 or c/5 rates.

(2) The highest on-charge cell voltage reached by trickle charge stored cells was 1.50 while charging at the c/5 rate.

d. During the overcharge test after the third 1-year storage periods:

(1) Only one of the open circuit stored cells exceeded 1.55 volts when the rate was increased from c/20 to c/10. This occurred only during the first hour following the increase in charge rate; the voltage then dropped to 1.55 volts and gradually continued to decline to 1.41 volts just prior to the beginning of the c/5 overcharge rate.

(2) The highest on-charge cell voltage reached by trickle charge stored cells was 1.43 while charging at both the c/10 and the c/5 rate.

e. During the overcharge test after the fourth 1-year storage period:

(1) Only one of the open circuit stored cells exceeded 1.55 volts at the c/10 rate. It was removed from the charging circuit after 41 hours of charges and was not subjected to overcharging at the c/5 rate.

(2) The highest on-charge cell voltage reached by trickle charged stored cells was 1.38 while charging at the c/5 rate.

3. The average on-charge voltages during the overcharge periods of the cells stored under each of the storage methods are shown graphically in Figure 4 and 4A. These graphs indicate that:

a. Under either method of storage, the average of the on-charge cell voltages are higher during the overcharge period before start of the storage test than during the overcharge periods following any of the four 1-year storage periods.

b. Under the open circuit storage method, the average of the on-charge voltages during the overcharge periods following each 1-year storage period was less than that of the previous year for the first 2 years. However this trend was broken in the third year. The average on-charge voltage during this overcharge period lies between initial (acceptance) values and those of the second 1-year period.

c. Under the trickle charge storage method, at the end of the first 1-year storage period, the overcharge voltages averaged considerably less than those of the initial acceptance testing. After the second 1-year storage period, the on-charge voltages had increased until they were only slightly less than those of the initial acceptance overcharge tests. After the third 1-year storage period, the on-charge cell voltages average slightly more than the first 1-year period and slightly less than the second 1-year period. After the fourth 1-year storage period, the on-charge cell voltage average less than the three previous 1-year periods.

F. Internal Resistance Test:

1. This test was performed to determine the internal resistance of the cells.

2. At the completion of the overcharge test; the cells were returned to the c/20 charging rate and given a short pulse (5-10 seconds) at the c/1 charge rate. The cell voltages, V_1, immediately prior to the pulse; and V_2, 5 milliseconds after the initiation of the pulse were read on a CEC high-speed oscillograph recorder (16.0 inches of tape per second). The internal resistance of the cell in ohms was calculated according to the following formula:

$$R = \frac{V_2 - V_1}{I_c - I_c/20}$$

V_1 and V_2 are in volts (read to the nearest 0.01 volt); I_c and $I_c/_{20}$ are in amperes (read to the nearest 0.001 ampere).

3. The internal resistance value for each cell is shown in Table IV. Due to the number of significant figures in the voltage measurements, the error in the resistance values is very large (on the order of 10 milliohms). Therefore, it is difficult to obtain any meaningful results for comparative purposes from the resistance data as computed. For these reasons, a Hewlett-Packard 4328A milliohmmeter was employed to measure the internal resistance directly in an effort to furnish more reliable data for present and future comparisons.

G. Visual Postmortem:

1. Following completion of tests after the fourth 1-year storage period, cell A2508 from the open circuit portion and cell A2544 from the c/100 trickle charge portion of the 1-year test were opened.

a. The cell subjected to the open circuit test had the following visual characterietics:

(1) The separator material was very dry, with brown discoloration spots near center of roll. The reason for these variations was the inactivity of these cells resulting in improper electrolyte distribution.

(2) Migration was more extensive in the wet portions of the separator material and under the scoring areas.

(3) Both positive and negative plates displayed less than normal flexibility with no visible loss of active material.

b. The cell subjected to the c/100 trickle charge test had the following visual characteristics:

(1) The moisture content was uniform throughout the separator material; a result of continual redistribution of electrolyte.

(2) Migration was more extensive and more general than that found in cell A-2508. The migration was heaviest in the scored areas.

(3) Both positive and negative plates displayed normal flexibility with pin holes of missing active material within a diagonal crease at the inner position of the positive plate.

2. Following completion of tests after the third 1-year storage period cell A-2495 from the open circuit portion and A-2547 from the c/100 trickle charge portion of the 1-year test were opened.

a. The cell subjected to the open circuit test had the following visual characteristics:

(1) The separator material was very dry in spots and somewhat leathery with very light yellowish discolorations in the wet areas. The reason for these variations was the inactivity of these cells resulting in improper electrolyte distribution.

(2) Migration was more extensive in the wet portions of the separator material and under the scoring area.

(3) Both positive and negative plates displayed normal flexibility with no visible loss of active material.

b. The cell subjected to the c/100 trickle charge test had the following visual characteristics:

(1) The moisture content was uniform throughout the separator material; a result of continual redistribution of electrolyte.

(2) Migration was more extensive and more general than that found in cell A-2495. The migration was heaviest in the scored areas.

(3) Both positive and negative plates displayed normal flexibility with no visible loss of active material.

3. Following completion of tests after the second 1-year storage period, cell A-2526 from the open circuit portion and cell A-2559 from the c/100 trickle charge portion of the 1-year portion of the 1-year test were opened.

a. The cell subjected to the open circuit test had the following visual characteristics:

(1) The separator material was considerably less pliable than normal with considerable migrated active material on the side adjacent to the positive plate. The heaviest migration was under the scoring area.

(2) The positive plate had normal flexibility with no visible loss of active material.

b. The cell subjected to the c/100 trickle charge test had the following visual characteristics:

(1) The separator material was very pliable with very little migration on any portion of the separator.

(2) The positive plate was less flexible than normal and had little visible loss of active material.

4. For pusposes of comparison, the following information on the postmortem of cells A-2536 and A-2564 following completion of tests after the first 1-year storage period is given.

a. Cell A-2536, subjected to the open circuit test had the following visual characteristics:

(1) The separator material was considerably less pliable than normal with considerable migration against the positive plate. The heaviest migration was under the scoring area.

(2) The positive plate was less flexible than normal and had little visible loss of active material.

(3) The negative plate had normal flexibility but had a discoloration on approximately 1/3 of the plate length starting at the center of the core.

b. Cell A-2564, subjected to the c/100 trickle charge test had the following visual characteristics:

(1) The separator material was very pliable with very little migration on any portion of the separator.

(2) The positive plate had normal flexibility with no visible loss of active material.

(3) The negative plate had normal flexibility with no visible discoloration.

TABLE I
TESTS: INITIAL AND AFTER OVERCHARGE
PHENOLPHTHALEIN

Group on Yearly Open Circuit Stand

Cell Number	Initial				After Overcharge				Immersion**
	Terminals		Seals		Terminals		Seals		
	+	-	Top	Other	+	-	Top	Other	
A-2491	v.s.								
A-2492	L				L				
*A-2493	L								
*A-2494	L				L				
A-2498	L				v.s.				
A-2503	L				L				
A-2508	L				L				

Group on Yearly Trickle Charge

Cell Number	Initial Terminals +	Initial Terminals -	Initial Seals Top	Initial Seals Other	After Overcharge Terminals +	After Overcharge Terminals -	After Overcharge Seals Top	After Overcharge Seals Other	Immersion**
*A-2540	v.s.				L				
*A-2542	L				L				
*A-2544	L				L				
*A-2545	L				v.s.				
A-2546	L								
A-2548					L				
A-2557	v.s.				v.s.				

L-Definite Leak
v.s. - Very Slight

**Immersion tests gave no indication of leaks. The phenolphthalein tests are much more sensitive.

*Indicates excess deposits positive terminal.

TABLE II
CAPACITY TESTS

Cell Number	Before Storage Periods Ampere-Hours			After First 1-Year Storage Period Ampere-Hours			After Second 1-Year Storage Period Ampere-Hours		
	1st	2nd	3rd	Without Charge 1st	After Recharge 2nd	After Recharge 3rd	Without Charge 1st	After Recharge 2nd	After Recharge 3rd
1-YEAR OPEN CIRCUIT STANDS									
A-2491 ●	4.34	4.29	4.11	2.01	3.90	3.55	1.54	3.50	3.50
A-2492 □	4.06	4.15	4.03	0.02	2.73	3.68	0.00	3.70	3.64
A-2493 △	3.64	3.50	3.33	2.13	3.46	3.29	1.84	3.24	3.22
A-2494 ▽	4.11	4.06	3.94	2.33	3.71	3.58	1.79	3.26	3.32
A-2495 ○	2.98	2.80	2.58	0.02	2.33	2.22	0.04	1.83	0.74
A-2498 X	3.69	3.37	3.17	1.72	3.71	3.26	2.31	3.76	3.36
A-2503 ◇	4.29	4.17	3.80	2.01	3.70	3.26	0.00	2.97	2.80
A-2508 ♡	3.89	3.97	3.80	2.37	3.42	3.23	1.70	3.10	3.01
A-2526 ⊕	4.15	4.06	3.97	2.28	4.03	3.85	1.61	2.71	3.36
A-2536	3.82	3.64	3.36	1.31	3.38	3.06	--	--	--
AVERAGE	3.90	3.80	3.61	1.62	3.54	3.30	1.20	3.12	2.99
PERCENT	100.0	97.5	92.5	41.5	90.8	84.6	30.7	80.0	76.8
1-YEAR OVERCHARGE PERIODS AT c/100									
A-2540 ●	3.99	3.99	3.99	3.24	2.75	2.83	3.12	2.97	3.10
A-2542 □	4.17	4.15	3.89	2.65	2.21	2.45	3.18	2.93	3.03
A-2544 △	3.99	3.82	3.73	3.20	2.61	2.59	2.28	2.31	2.33
A-2545 ▽	3.78	3.50	3.25	2.97	2.21	2.18	3.21	2.86	2.76
A-2546 ○	4.41	4.20	3.80	2.83	2.43	2.51	2.98	2.93	3.03
A-2547 X	3.50	3.20	2.92	2.33	1.75	1.77	2.28	2.02	2.06
A-2548 ◇	3.81	3.75	3.47	3.38	2.71	2.47	2.76	1.68	2.84
A-2557 ♡	3.76	3.80	3.54	3.73	2.89	2.85	3.21	3.15	3.29
A-2559 ⊕	3.76	3.90	3.76	3.73	2.85	2.74	3.29	2.42	3.18
A-2564	4.03	3.82	3.59	2.53	2.14	2.15	--	--	--
AVERAGE	3.92	3.81	3.59	3.06	2.45	2.45	2.92	2.59	2.85
PERCENT	100.0	97.2	91.6	78.0	62.5	62.5	74.5	66.5	72.7

TABLE II (cont)
CAPACITY TESTS

	Cell Number	After Third 1-Year Storage Period Ampere-Hours Without Charge 1st	After Recharge 2nd	After Recharge 3rd	After Fourth 1-Year Storage Period Ampere-Hours Without Charge 1st	After Recharge 2nd	After Recharge 3rd
1-YEAR OPEN CIRCUIT STANDS	A-2491 ●	0.79	3.18	2.94	0.67	3.03	2.86
	A-2492 □	0.05	3.45	3.27	0.00	3.76	3.53
	A-2493 △	0.00	3.50	3.27	0.00	3.65	3.47
	A-2494 ▽	0.00	3.15	2.54	0.00	2.89	2.83
	A-2495 ○	0.00	2.05	1.72			
	A-2498 ×	1.35	3.20	2.97	0.00	3.88	3.59
	A-2503 ◇	0.00	2.57	2.18	0.00	2.48	2.51
	A-2508 ♡	0.00	3.20	2.36	0.00	2.98	2.80
	A-2526 ⊕	--	--	--			
	A-2536	--	--	--			
	AVERAGE	0.27	3.04	2.66	0.096	3.24	3.08
	PERCENT	1.0	77.9	68.2	0.03	83.0	78.9
1-YEAR OVERCHARGE PERIODS AT c/100	A-2540 ●	3.77	3.21	3.29	3.59	3.27	3.15
	A-2542 □	3.55	3.02	2.80	3.41	3.18	2.96
	A-2544 △	3.24	2.76	2.40	2.25	2.54	2.39
	A-2545 ▽	3.72	3.02	2.68	3.35	3.09	3.03
	A-2546 ○	3.29	2.66	2.50	2.60	2.80	2.13
	A-2547 ×	1.97	2.05	1.67			
	A-2548 ◇	3.27	2.76	2.57	2.92	3.09	2.89
	A-2557 ♡	3.54	3.33	3.20	3.09	3.54	3.33
	A-2559 ⊕	--	--	--			
	A-2564	--	--	--			
	AVERAGE	3.30	2.85	2.64	3.03	3.07	2.84
	PERCENT	84.2	72.7	67.3	77.3	78.2	72.5

TABLE III
CELL SHORT TEST
RECOVERY VOLTAGES

Cell Number	Before Storage Test	After First 1-Year Storage Test	After Second 1-Year Storage Test	After Third 1-Year Storage Test
A-2491	1.21	1.20	1.20	1.20
A-2492	1.23	1.21	0.02	0.01
A-2493	1.23	1.21	1.21	1.21
A-2494	1.22	1.22	1.21	1.21
A-2495	1.22	1.20	1.19	1.21
A-2498	1.22	1.22	1.20	1.19
A-2503	1.22	1.21	1.22	1.21
A-2508	1.22	1.21	0.00	0.01
A-2526	1.22	1.20	*	--
A-2536	1.23	1.22	--	--
AVERAGE	1.22	1.21		.906**
A-2540	1.23	1.20	1.21	1.21
A-2542	1.22	1.19	1.21	1.19
A-2544	1.22	1.22	1.20	1.19
A-2545	1.22	1.22	1.23	1.21
A-2546	1.23	1.19	1.20	1.20
A-2547	1.22	1.23	1.24	1.23
A-2548	1.24	1.22	1.23	1.23
A-2557	1.22	1.21	1.21	1.21
A-2559	1.21	1.21	1.22	--
A-2564	1.23	1.23	--	--
AVERAGE	1.22	1.21	1.217	1.21

* Missed in error
**Average without low cells - 1.21 volts

TABLE III (contd)
CELL SHORT TEST
RECOVERY VOLTAGES

Cell Number	After Fourth 1-Year Storage Test
A-2491	1.20
A-2492	0.01
A-2493	1.22
A-2494	0.00
A-2498	1.21
A-2503	0.21
A-2508	0.00
AVERAGE	0.55
A-2540	1.21
A-2542	1.19
A-2544	1.17
A-2545	1.21
A-2546	1.21
A-2548	1.22
A-2557	1.18
AVERAGE	1.20

TABLE IV
INTERNAL RESISTANCE (Milliohms)

Cell Number	Before Storage Test	After First 1-Year Storage Test	After Second 1-Year Storage Test	After Third 1-Year Storage Test Compu-tation	After Third 1-Year Storage Test Milliohm-meter
A-2491	6.02	12.03	12.04	9.03	13.4
A-2492	9.02	12.03	12.04	9.03	16.0
A-2493	15.03	18.04	15.05	6.02	21.5
A-2494	6.02	15.03	12.04	6.02	15.0
A-2495	6.02	18.04	21.07	15.0	14.8
A-2498	6.02	18.04	6.02	9.03	27.6
A-2503	9.02	15.03	15.05	12.0	14.5
A-2508	9.02	12.03	9.03	9.03	13.6
A-2526	3.01	12.03	6.02	--	--
A-2536	3.01	12.03	--	--	--
AVERAGE	7.22	14.43	12.04	9.40	17.1
A-2540	6.02	15.03	6.02	9.03	15.0
A-2542	3.01	15.03	12.04	3.01	11.5
A-2544	6.02	15.03	15.05	6.02	14.5
A-2545	6.02	18.04	9.03	3.01	18.0
A-2546	3.01	15.03	12.04	3.01	36.0
A-2547	6.02	21.05	21.07	9.03	13.5
A-2548	6.02	15.03	9.03	6.02	16.0
A-2557	6.02	15.03	15.05	6.02	19.5
A-2559	3.01	18.04	9.03	--	--
A-2564	3.01	15.03	--	--	--
AVERAGE	4.81	16.23	12.04	5.64	18.0

TABLE IV (contd)
INTERNAL RESISTANCE (Milliohms)

Cell Number	After Fourth 1-Year Storage Test Compu-tation	Milliohm-meter
A-2491	30.90	32.5
A-2492	30.60	13.1
A-2493	10.50	14.6
A-2494	30.30	40.0
A-2498	10.50	14.1
A-2503	20.40	16.6
A-2508	50.40	68.8
AVERAGE	26.23	28.5
A-2540	18.04	15.8
A-2542	20.71	23.4
A-2544	30.90	35.0
A-2545	18.04	15.8
A-2546	30.08	29.4
A-2548	20.71	18.8
A-2557	20.10	16.4
AVERAGE	22.65	22.1

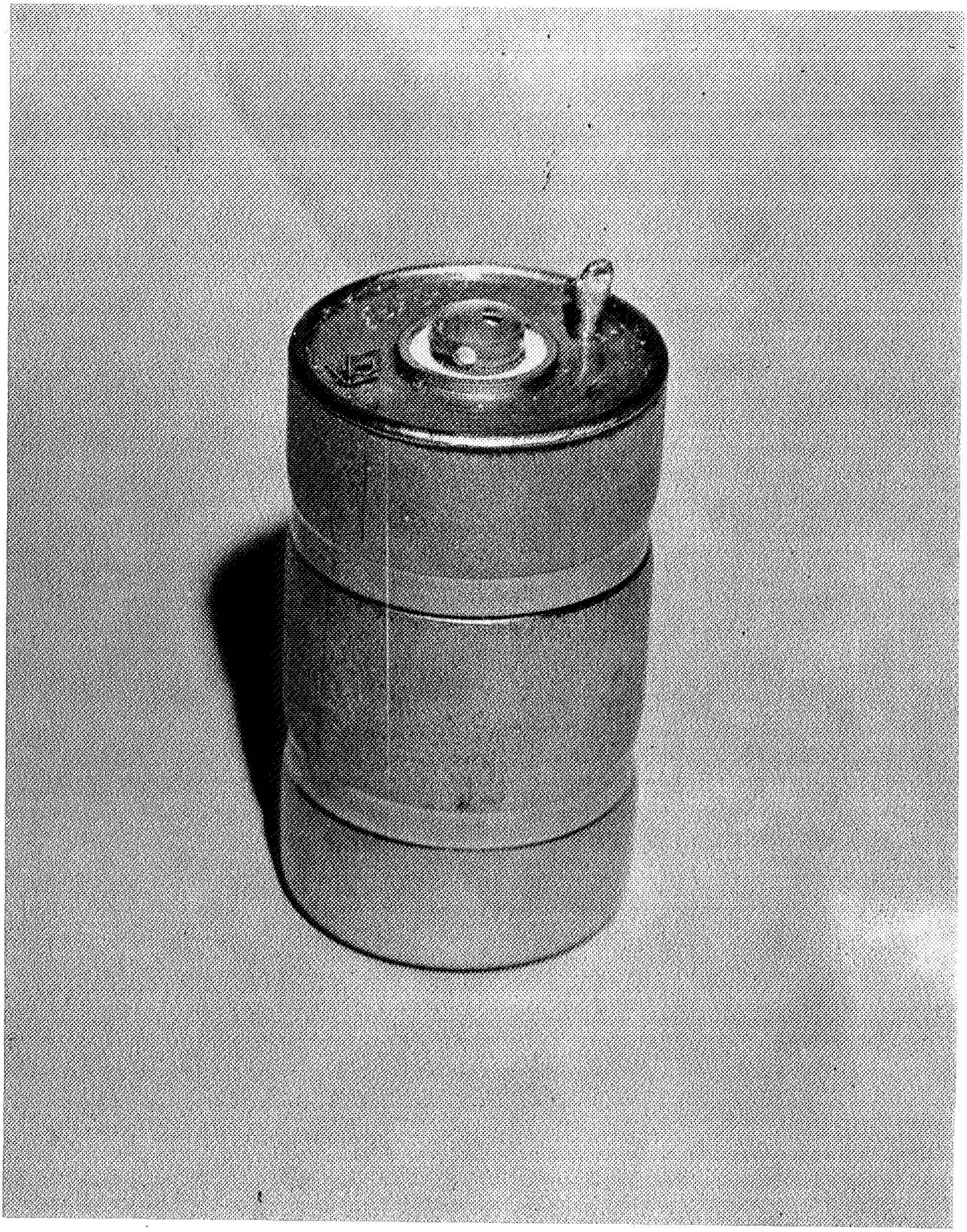
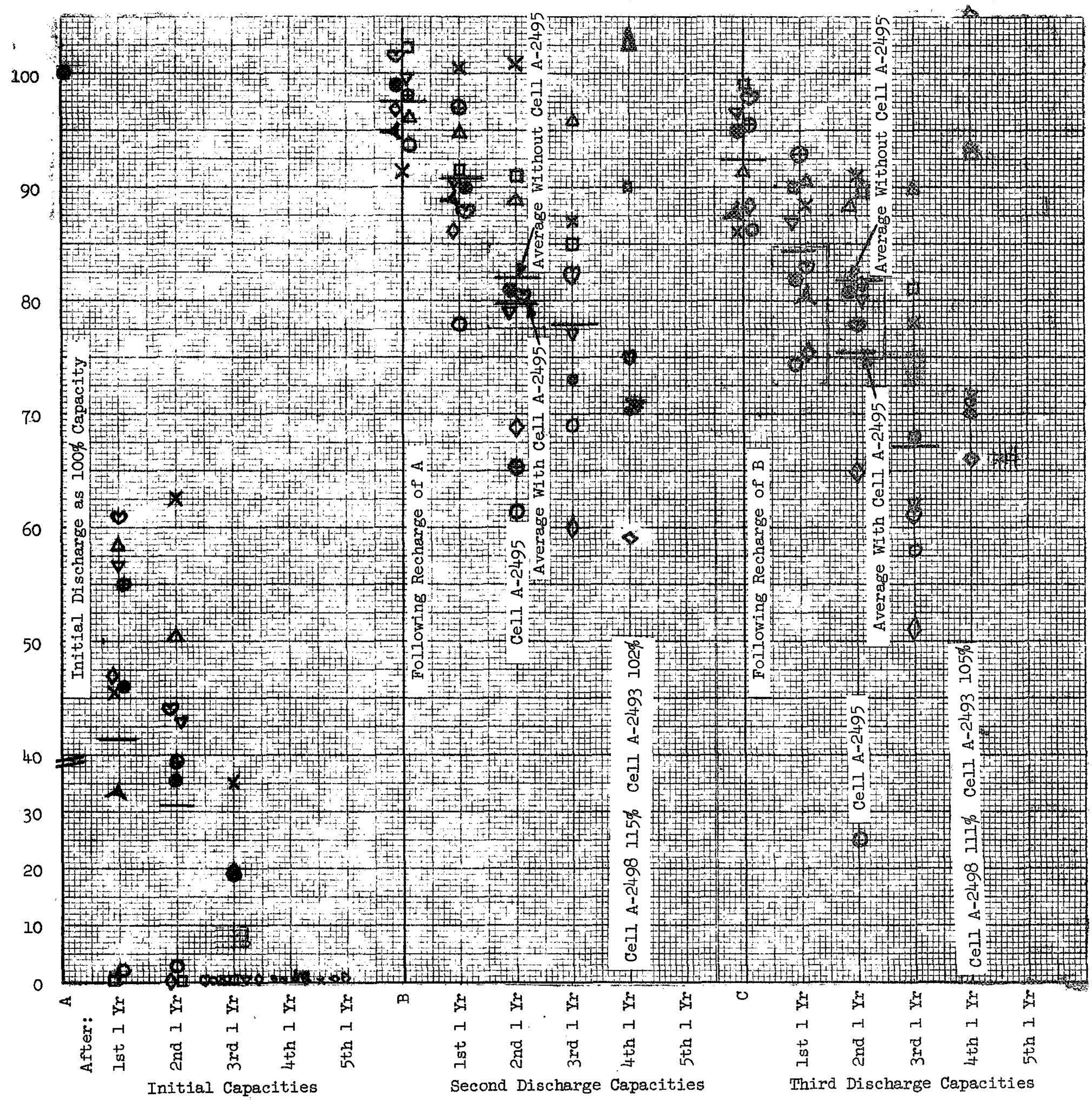


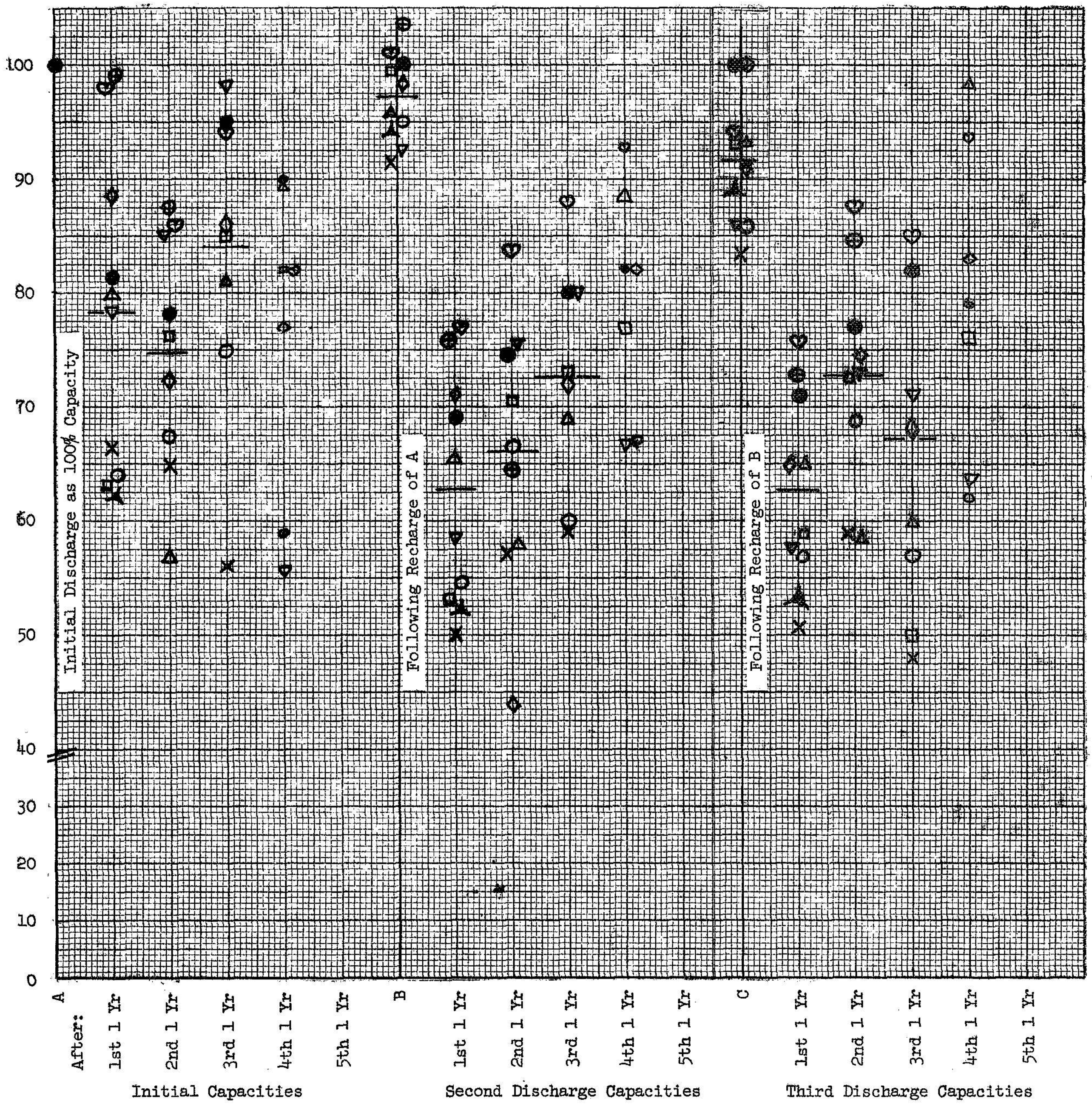
FIGURE 1



OPEN CIRCUIT STORAGE TEST AT 25° ± 2° C

INITIAL AND TWO REPEAT CAPACITY TESTS AFTER EACH YEAR OF OPEN CIRCUIT STORAGE
(Each capacity test shown as percentage of initial discharge.)

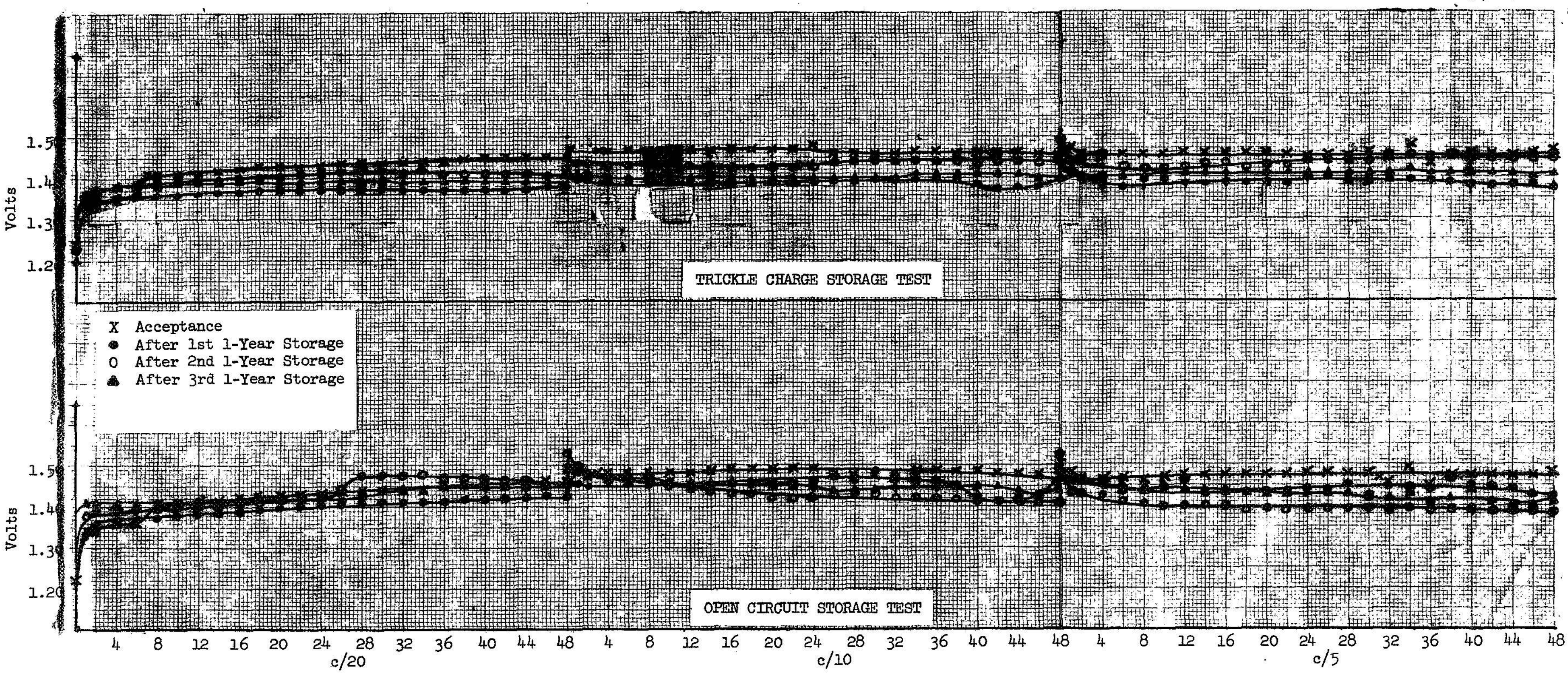
FIGURE 2



TRICKLE CHARGE STORAGE TEST AT 25° ± 2° C

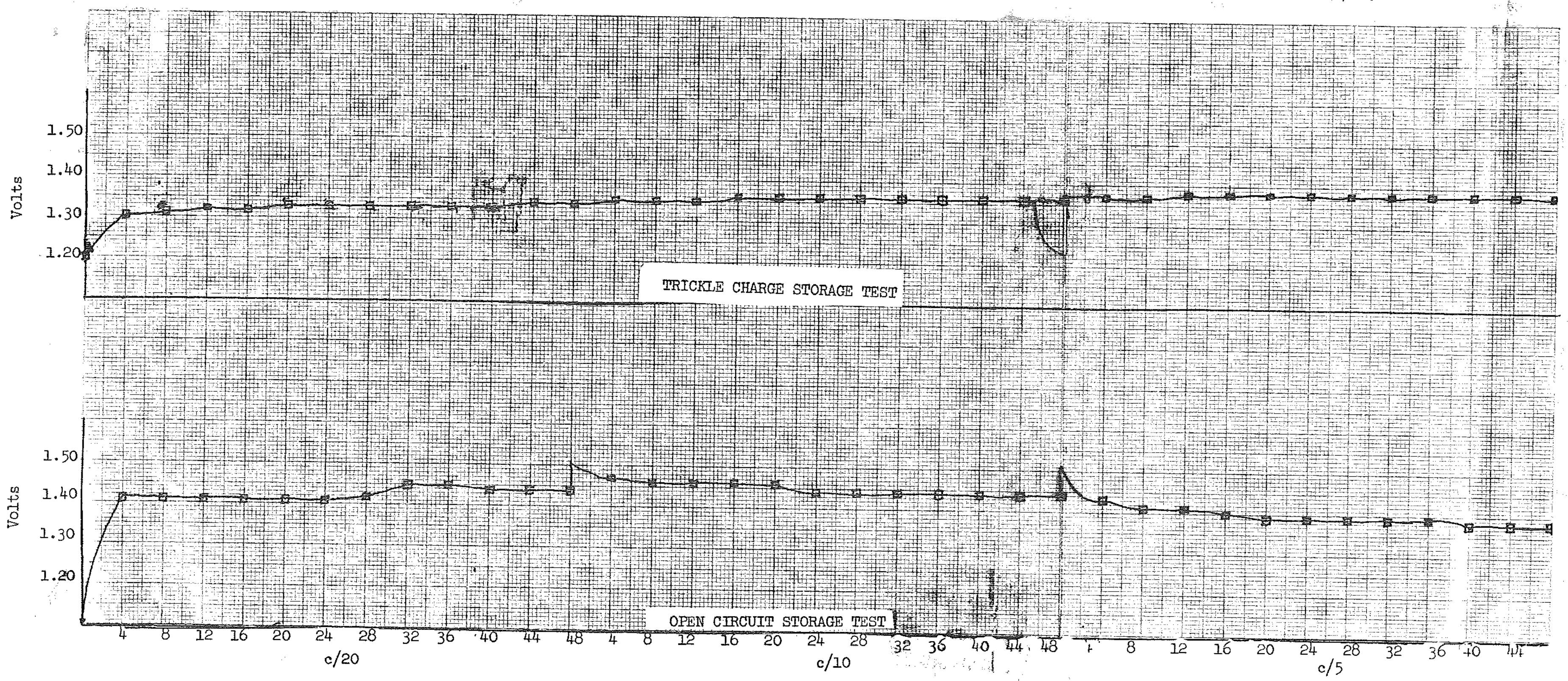
INITIAL AND TWO REPEAT CAPACITY TESTS AFTER EACH YEAR OF TRICKLE CHARGE STORAGE
(Each capacity test shown as percentage of initial discharge.)

FIGURE 3



OVERCHARGE VOLTAGES (AVERAGE) VERSUS TIME AT c/20, c/10 AND c/5

FIGURE 4



OVERCHARGE VOLTAGES (AVERAGE) VERSUS TIME AT c/20, c/10 AND c/5

FIGURE 4A

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